Development of an effective finite-rate oxidation model for NuSil-coated charred carbon preform ablators

K. Swaminathan Gopalan[1,a)] and A. Borner[1]

[1] *AMA at NASA Ames Research Center, Moffett Field, CA 94035, USA.*

[a)] Corresponding author: krishnan.swaminathan-gopalan@nasa.gov

Recently, a detailed effective finite-rate surface chemistry model was developed for the oxidation of FiberForm [1] using the molecular beam experimental data of Poovathingal et al., [2]. FiberForm is the major building block of the thermal protection system (TPS) material Phenolic Impregnated Carbon Ablator (PICA), commonly used by NASA. The surface chemistry model consists of detailed surface reaction mechanisms such as adsorption, desorption, and several types of Langmuir-Hinshelwood (LH) reactions to characterize the oxygen-carbon interactions at the surface. This model provides excellent agreement with the experimental data for oxidation product compositions and corresponding translational energy distributions. Further, an effective oxidation model was constructed that captures the equivalent interaction of oxygen inside the microstructure (including multiple surface collisions) via a modified reactivity for a smooth wall boundary condition. This enables the use of this model directly into Computational Fluid Dynamics (CFD) codes and Material Response (MR) codes to accurately simulate the gas–surface interactions within FiberForm without using the detailed micro-structure.

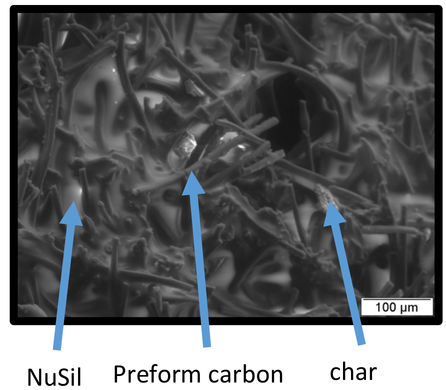

Fig. 1. SEM image of NuSil-coated PICA with charring–courtesy of Brody.K.Bessire.

However, this effective model is valid only for the virgin FiberForm. As the TPS material undergoes ablation, the preform carbon burns and turns into char. In addition, PICA is also coated with a protective silicon coating called NuSil for the purpose of mitigating the spread of phenolic dust, and limit contamination during clean room operations. Fig. 1 shows a X-ray microtomography image of a charred NuSil-coated PICA. The NuSil layer introduces species containing silicon into the product mixture. Further, the reactivity of the carbon within the char layer is different from the virgin FiberForm as shown in Fig. 2. Recently a new set of molecular beam experiments were performed on this NuSil-coated TPS material [3] with the same type of oxygen beam used in the previous experiments. Using the latest experimental data, the previously developed effective model will be extended to account for the charred carbon as well as the NuSil coating. Finally, this new effective model with three phases – preform carbon, char, and NuSil; will be compared and validated against the experimental product compositions.

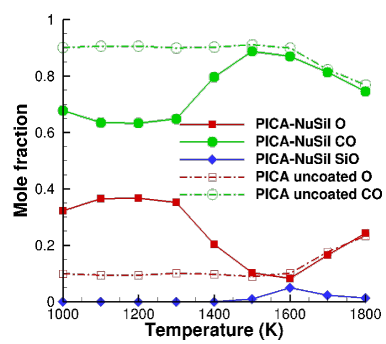

Fig. 2. Mole fraction of reaction products scattered from NuSil-coated and uncoated PICA surface.

ACKNOWLEDGEMENTS

This work is supported through contract NNA15BB15C to AMA, Inc. from the Entry Systems Modeling project (Michael D. Barnhardt project manager, Aaron M. Brandis principal investigator) as part of the NASA Game Changing Development (GCD) program of NASA's Space Technology Mission Directorate. The authors would also like to thank Prof. Minton and his group at UC Boulder for providing the data and useful discussions.

REFERENCES

[1] Gopalan, Krishnan Swaminathan, et al. "Gas–surface interactions in lightweight fibrous carbon materials." Computational Materials Science 205 (2022): 111190.
[2] Poovathingal, Savio J., et al. "Reactive and inelastic scattering dynamics of hyperthermal O and O2 from a carbon fiber network." Carbon 183 (2021): 277-290.
[3] Chen, D., Xu, C., & Minton, T. (2021). Effect of Silicone Coating on Atomic Oxygen Reactivity with Carbon Fiber Preform and Phenolic Impregnated Carbon Ablator.